NRL Report 7437

Proportioning Characteristics of Aqueous Film-Forming Foam Concentrates

R. L. GIPE AND H. B. PETERSON

Chemical Dynamics Branch
Chemistry Division

July 20, 1972

NAVAL RESEARCH LABORATORY
Washington, D.C.

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author) Naval Research Laboratory Washington, D.C. 20390	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3 REPORT TITLE

PROPORTIONING CHARACTERISTICS OF AQUEOUS FILM-FORMING FOAM CONCENTRATES

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

An interim report on a continuing NRL problem.

5 AUTHOR(S) (First name, middle initial, last name)

R. L. Gipe and H. B. Peterson

6 REPORT DATE July 20, 1972	7a. TOTAL NO OF PAGES 30	7b. NO. OF REFS
8a. CONTRACT OR GRANT NO NRL Problem C05-19.203 b. PROJECT NO. S-4643-12081 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NRL Report 7437 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	

10 DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Department of the Navy (Naval Ship Systems Command), Washington, D.C. 20360

13 ABSTRACT

Aqueous Film-Forming Foam (AFFF) has now widely replaced protein-type foam in the Navy for fire suppression purposes. Because this changeover has been accompanied by very little change in the mechanical equipment, there has been a need to study the full impact of using AFFF in equipment designed for protein foam. One of the areas studied and covered in this report is concerned with the proportioning equipment used to inject foam concentrate into a fire main to form a 6% solution at fixed flow rates, variable flow rates, or both.

The early AFFF concentrates differ from the later ones in one physical property which affects their proportioning characteristics, i.e., viscosity. FC-194 and FC-195 brands of AFFF concentrates are more viscous (ca. 100 cS) than the protein foam concentrate (20 cS), while the new FC-196, FC-199, and FC-200 brands are less viscous (5 cS). Viscosity-temperature relationships are given for all these materials.

It was found that in certain types of proportioning equipment, such as nozzle eductors and simple orifices, solution strength is inversely related to viscosity so that lower viscosities produce higher solution concentrations. In other types of proportioning equipment in naval service, e.g., water-motor proportioners, an intermediate viscosity produces optimum results, and deviations to either higher or lower viscosities cause a reduction in solution concentration. By operating the equipment with a wide range of concentrate viscosities, it was possible to establish the proper viscosity for optimum operation as being between 20 and 80 cS.

Also studied were the use of booster pumps to supercharge the proportioner pump inlet and the use of positive displacement injection pumps for systems with fixed flows, such as the flush-deck nozzles on aircraft carrier flight decks. In the latter equipment, concentrate viscosity was found to be a less critical factor in pump performance. Concentrate viscosity was found, however, to be a factor in setting the pump's internal pressure regulating valve.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801

Security Classification

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Aqueous Film-Forming Foam Fire extinguishment Proportioning characteristics						

CONTENTS

ABSTRACT

Aqueous Film-Forming Foam (AFFF) has now widely replaced protein-type foam in the Navy for fire suppression purposes. Because this change-over has been accompanied by very little change in the mechanical equipment, there has been a need to study the full impact of using AFFF in equipment designed for protein foam. One of the areas studied and covered in this report is concerned with the proportioning equipment used to inject foam concentrate into a fire main to form a 6% solution at fixed flow rates, variable flow rates, or both.

The early AFFF concentrates differ from the later ones in one physical property which affects their proportioning characteristics, i.e., viscosity. FC-194 and FC-195 brands of AFFF concentrates are more viscous (ca. 100 cS) than the protein foam concentrate (20 cS), while the new FC-196, FC-199, and FC-200 brands are less viscous (5 cS). Viscosity-temperature relationships are given for all these materials.

It was found that in certain types of proportioning equipment, such as nozzle eductors and simple orifices, solution strength is inversely related to viscosity so that lower viscosities produce higher solution concentrations. In other types of proportioning equipment in naval service, e.g., water-motor proportioners, an intermediate viscosity produces optimum results, and deviations to either higher or lower viscosities cause a reduction in solution concentration. By operating the equipment with a wide range of concentrate viscosities, it was possible to establish the proper viscosity for optimum operation as being between 20 and 80 cS.

Also studied were the use of booster pumps to supercharge the proportioner pump inlet and the use of positive displacement injection pumps for systems with fixed flows, such as the flush-deck nozzles on aircraft carrier flight decks. In the latter equipment, concentrate viscosity was found to be a less critical factor in pump performance. Concentrate viscosity was found, however, to be a factor in setting the pump's internal pressure regulating valve.

PROBLEM STATUS

This is an interim report; work on the problem is continuing.

AUTHORIZATION

NRL Problem C05-19.203
Project S-4643-21081

Manuscript submitted April 26, 1972.

PROPORTIONING CHARACTERISTICS OF AQUEOUS FILM-FORMING FOAM CONCENTRATES

INTRODUCTION

The introduction of Aqueous Film-Forming Foam (AFFF) into naval fire-fighting applications took place at a point when this material was still undergoing a period of rapid technical development. As a result, there presently exists within the Navy several different formulations of concentrate, and although possessing quite similar fire suppression capabilities, they do differ in one physical characteristic — viscosity. This property is very important because it bears on the handling and proportioning of these materials in fire suppression systems in a manner to be discussed in this report. Also, these new products are being used primarily in "on-hand" equipment designed for operation with protein-type foam concentrate which also has still different viscosity characteristics.

BACKGROUND

Chronological Development of Concentrates

The first AFFF introduced into the naval fire-fighting service in 1964 was designated as FC-183 by its producer, the 3M Company. It was a highly viscous liquid designed to be premixed in a 25% concentration in fresh water and blown with propellant liquid 12, also known as dichlorodifluoromethane. This material is now regarded as obsolete and should be discarded if found. FC-183 was replaced with FC-194 which had a lower viscosity and was designed to be used at a strength of 6% in fresh water in conventional foam-making equipment. Because the fire suppression performance of FC-194 diminished when it was diluted with seawater, this formulation was never used on ships except in certain equipment (MB-5 and Twinned Agent Unit) where dilution with fresh water could be assured.

To provide shipboard-installed fire extinguishing systems with the same increased capabilities afforded shore stations, a material fully compatible with seawater, FC-195, was developed and introduced onto ships for use in their High Capacity Fog Foam (HCFF) systems and for converting their NBC washdown network to fire-fighting systems. FC-195 was procured under a purchase description for aircraft carriers under urgent requirements prior to the preparation of a formal military specification and establishment of a Qualified Products List (QPL). In November 1969, specification MIL-F-24385 was issued; it covered an AFFF concentrate for use with either fresh water or seawater, and by May 1970, the first QPL approval was given to 3M Company's FC-196. FC-195 was never submitted for testing under the specification.

After experiencing several perforations of type 304 stainless-steel piping containing FC-195 into which seawater had inadvertently entered, it was anticipated that the FC-196 with an appreciable chloride content might cause similar adverse action on corrosion-resistant-steel (CRES) shipboard tanks, piping, or both. The characteristic low pH, 4.5,

of the concentrate, which in addition was well buffered, aggravates the potential corrosiveness. The 3M Company, at the Navy's behest, then prepared a chloride-free product similar to FC-196 which became FC-199 and obtained QPL status in March 1971. The blue plastic containers with this chloride-free concentrate were given a distinctive white band around the base for ease of identification.

A further modification in concentrate formulation was made to give it a pH greater than 7 and give it inhibitory properties for preventing the corrosion of stainless steel by seawater contamination. This concentrate became FC-200 and was approved in January 1972. Amendment 5 of February 17, 1972, disqualified all previously listed concentrates.

Occurrence of Concentrates

Because of the past history on procurement, it is to be expected that most shore activities will have some FC-194. Almost all of the FC-195 and FC-196 output was directed to ships and little, if any, should be encountered on air stations. Procurements from March 1971 to March 1972 have consisted of FC-199. FC-200 started reaching the Defense Supply system in March 1972 and will be the only concentrate in future production. The FC-183 should not be used and should be discarded if found. Protein-type foam is being phased out.

PROPORTIONING CONSIDERATIONS

Influence of Concentrate Viscosity

Currently there are two types of proportioning equipment found in the Navy. An example of one type of proportioner is the orifice which is found in the "MB" series of aircraft rescue and fire-fighting vehicles which utilize the foam pump. Proportioning is provided by allowing water and concentrate to flow from their respective tanks by gravity through orifice plates into the suction of the pump. The relative area of the two orifices is approximately 1:16 because the driving pressure differential across both is the same, i.e., gravitational force and hydraulic head. The liquid tanks are constructed of the same 1:16 relative cross-sectional area to maintain balanced hydraulic heads as the liquids are consumed.

A second variation of the orifice-type proportioner uses a pickup tube with portable nozzles attacked to handlines. A venturi built into the body of the nozzle provides a less-than-atmospheric pressure for the driving source and an orifice controls the rate of concentrate drawn into the low-pressure area. The total water flow is controlled by the nozzle inlet pressure and the jet orifice size. Concentrate is brought to the nozzle from 5-gal. containers which accept a pickup tube leading up to the eductor. In this type of device the lower the viscosity of fluid passing through the orifice, the higher its flow rate will be, if all other factors remain the same.

In the above described type of proportioner the strength of the solution output is inversely proportional to the viscosity of the concentrate, i.e., lower viscosity will result in greater strength solutions.

The second type of proportioner is the Hale or water-motor proportioner, widely used on shipboard in both portable and fixed systems. Here the concentrate is taken from a container and forced into the fire main against pressures of 120 to 175 psi by means of a positive displacement pump. The prime mover is a water motor in the fire-main flow stream turning at speeds directly proportional to the rates of flow and directly connected to the pump. A certain amount of the concentrate being pumped slips around the clearances at the ends and tips of the rotors and is "lost" from the output of the pump. The volume of this slip depends on the mechanical condition of the pump, the disch... pressure, and the viscosity of the material being pumped. The volume of slip pe... ...ge-wise on the pump output is much more evident at slow speeds. A low viscosity will permit a larger volume of slippage than a high viscosity. However, when the viscosity becomes too high, other factors such as cavitation enter the picture and the pump output will begin to drop again. Therefore, in this second type of proportioner an intermediate viscosity gives the best results.

Proper design can minimize the effects of the above factors when the viscosity of the material always remains the same. If, however, the liquid viscosity changes appreciably with temperature or a liquid different than the one designed for is used, then proportioning inaccuracies can be expected.

Water-Motor Proportioners

The water-motor proportioner described above comes in two different sizes. One has a working range of 60 to 180 gpm and is used as a portable unit connected in hose lines where it may supply one to three handline nozzles with solution, or is used in fixed systems for protecting shipboard machinery spaces.

The second size has a maximum flow-rated capacity of 1000 gpm and is used in the fixed systems supplying 6% solution to hydrants on the flight deck catwalk, hydrants on the hangar deck, and foam-water sprinklers or monitors on the hangar deck. The minimum flow rate varies with the particular model and is related to its slip characteristics. A second generation unit has a minimum rate of 400 gpm, while a third generation unit will go down to 200 gpm. However, with the introduction of AFFF there has been a desire to go to even lower flows of 60 gpm.

A retrofit has been made on the older aircraft carriers equipped with second generation proportioners to extend their lower flow limit. This modification consists of a centrifugal pump installed in the pump suction line between the concentrate tank and the proportioner which in effect supercharges the pump inlet pressure to 100 psi at low flow rates. At high flow rates, the booster pump restricts the flow; hence, a bypass line with a check valve is installed to overcome this restriction.

Plans are now underway to add booster pumps to the third generation proportioners as well to give them the capability of water flow rates down to 60 gpm. The booster pump evaluated here for this purpose was a turbine type with a water-rated capacity of 10 gpm at 170-psi pressure head. The second generation units will require similar booster pumps to obtain satisfactory operation down to 60 gpm.

Injection Pump Proportioning

Another example of the second type proportioner, wherein an intermediate viscosity gives optimum performance, is the injection pump (for AFFF concentrate). This pump is being used in the newly installed conversions of the aircraft carriers NBC washdown systems to fire suppression systems. Operation of these systems involves a fixed flow rate (except for pressure variations or plugged nozzles), and a positive-displacement pump can be selected to produce a 6% resultant solution. On the USS Coral Sea (CVA-43), for example, there are 22 zones or subsystems, each operating independently with its own pump. The pumps used to date for this service have all been of the sliding-vane type which are also subject to slip characteristics like the water-motor devices cited above.

The characteristics of the injection pump pressure control valve and a "bleeder" valve, as used, were also studied in this work as they related to concentrate viscosity.

EXPERIMENTAL RESULTS

Viscosity-Temperature Characteristics

Figure 1 is a plot of the data for viscosity as a function of temperature for protein foam and the recent AFFF concentrates.

Composite Viscosities

For the time that these different AFFF concentrates continue to exist in the inventory, it will be possible to intermix them in ready-use storage tanks. The viscosities of the mixtures of one combination are shown in Fig. 2. For practical purposes the mixtures can be considered to be madeup of high-viscosity type (FC-194 and FC-195) and low-viscosity type (FC-196, FC-199, and FC-200).

Concentrates

To encompass the full range of viscosities which could be encountered with the proportioning devices in normal service, four liquids, with one used at two different temperatures, were employed: FC-196 or FC-199 with a viscosity of 10 cS; protein foam, 20 cS; FC-195 at 65°F, 130 cS; and FC-195 at 43° to 48°F, 200 cS. Water with a viscosity of 1 cS was also used in some of the testing in place of AFFF concentrate.

Nozzle Eductor

The "NPU" nozzle is a standard 60-gpm portable, hose-line device used in the Navy which has an integral eductor for taking concentrate from a 5-gal. container. An in-line-type eductor would probably have similar characteristics. The data obtained with the NPU nozzle are given in Fig. 3, where the concentration of solution is given as a function of nozzle inlet pressure and concentrate viscosity. Concentrations were determined by measuring flow ratios and also by a refractometric method for the AFFF.

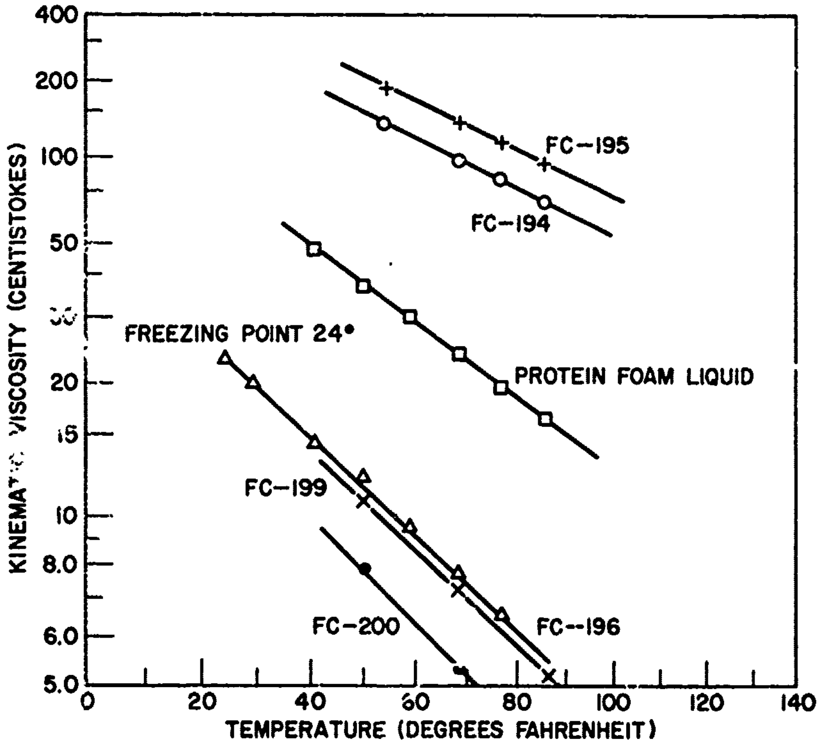


Fig. 1 — Viscosity-temperature relationships of AFFF and protein-type foam concentrates

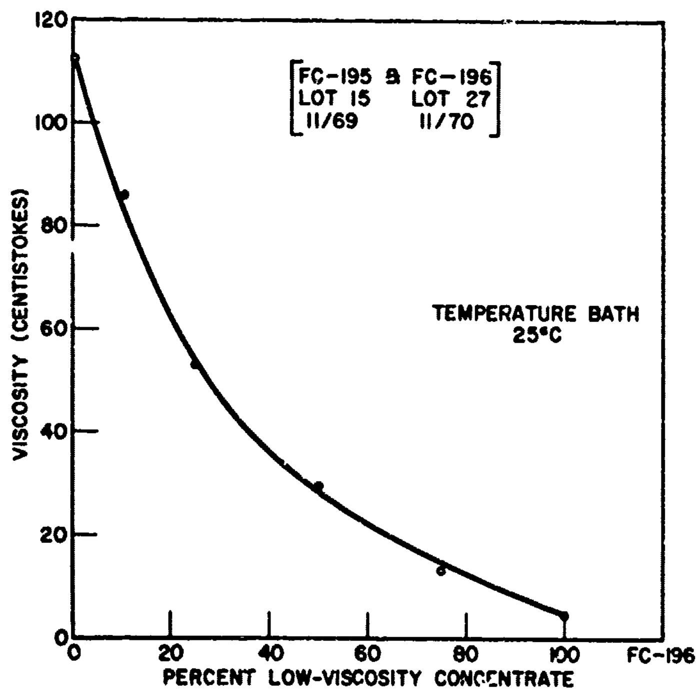


Fig. 2 — Viscosity characteristics of mixtures of high- and low-viscosity types of AFFF concentrates

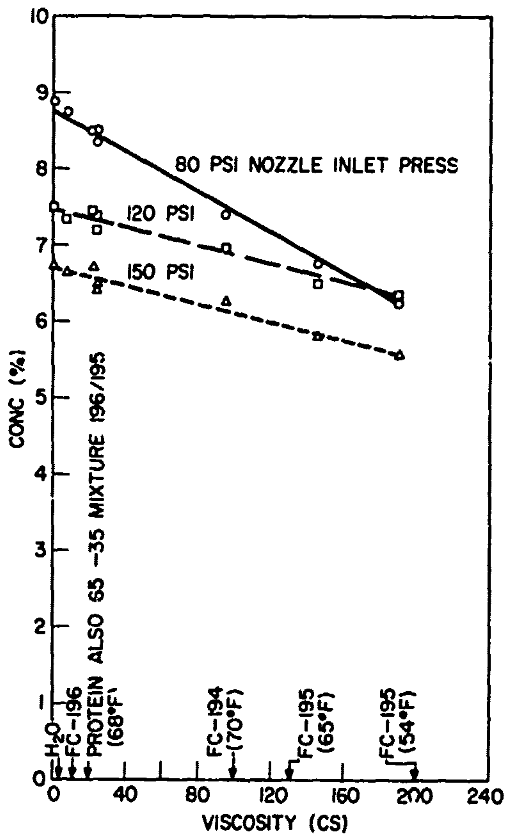


Fig. 3 — Concentration of resultant solution from a nozzle eductor as related to concentrate viscosity and nozzle inlet pressure

Small Water-Motor Proportioner

The particular unit used in making the test runs was a class FP-180, model 12MPD, bearing the serial number P623 and of unknown age. Although slightly worn, it was probably in better condition than most units to be found in the fleet. It had been recently reconditioned by the manufacturer and checked out as meeting specification requirements.

When putting the proportioner into operation, it is necessary to "wet" and "seal" the pump to allow it to prime by creating sufficient vacuum to draw concentrate from its container into the pump. This wetting is taken care of automatically by momentarily diverting a "slug" of water from the fire main into the pump suction and pickup tube as the selector cock handle is moved from the off position to the first on position. In effect, then, the pump always primes with water regardless of which concentrate is in the container on the deck. The minimum flow rate at which the pump could be primed and start pumping concentrate in this manner was determined at inlet pressures of 110 and 150 psi. These points and the solution concentrations observed as the flow rates increased are shown in Figs. 4 and 5, respectively.

The left-hand termination of the lightly lined curves indicates the lowest flow rates for initial water priming. Once priming had been accomplished, with the more viscous concentrates, the flow could be reduced down below the original priming flow rate. This

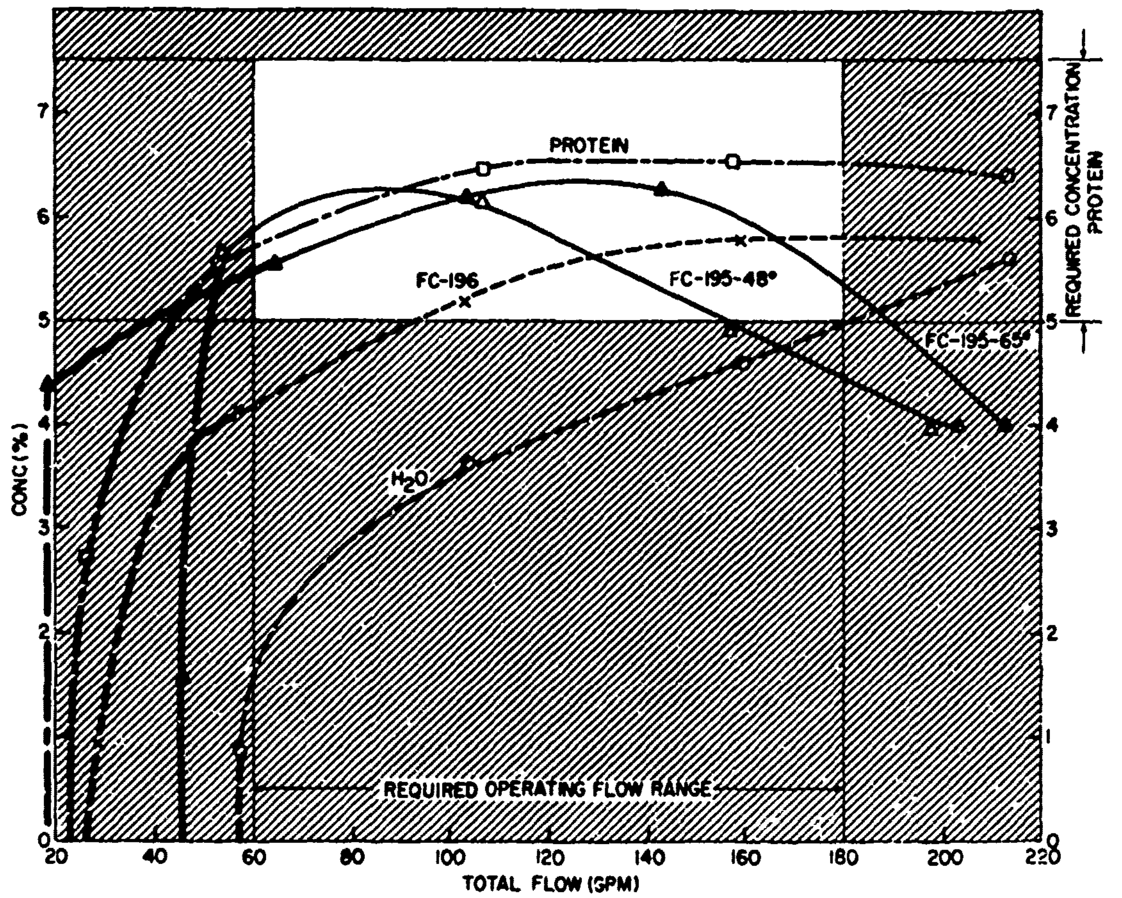


Fig. 4 — Concentration of resultant solution from class FP-180 proportioner as related to concentrate viscosity and flow rate with inlet pressure of 110 psi

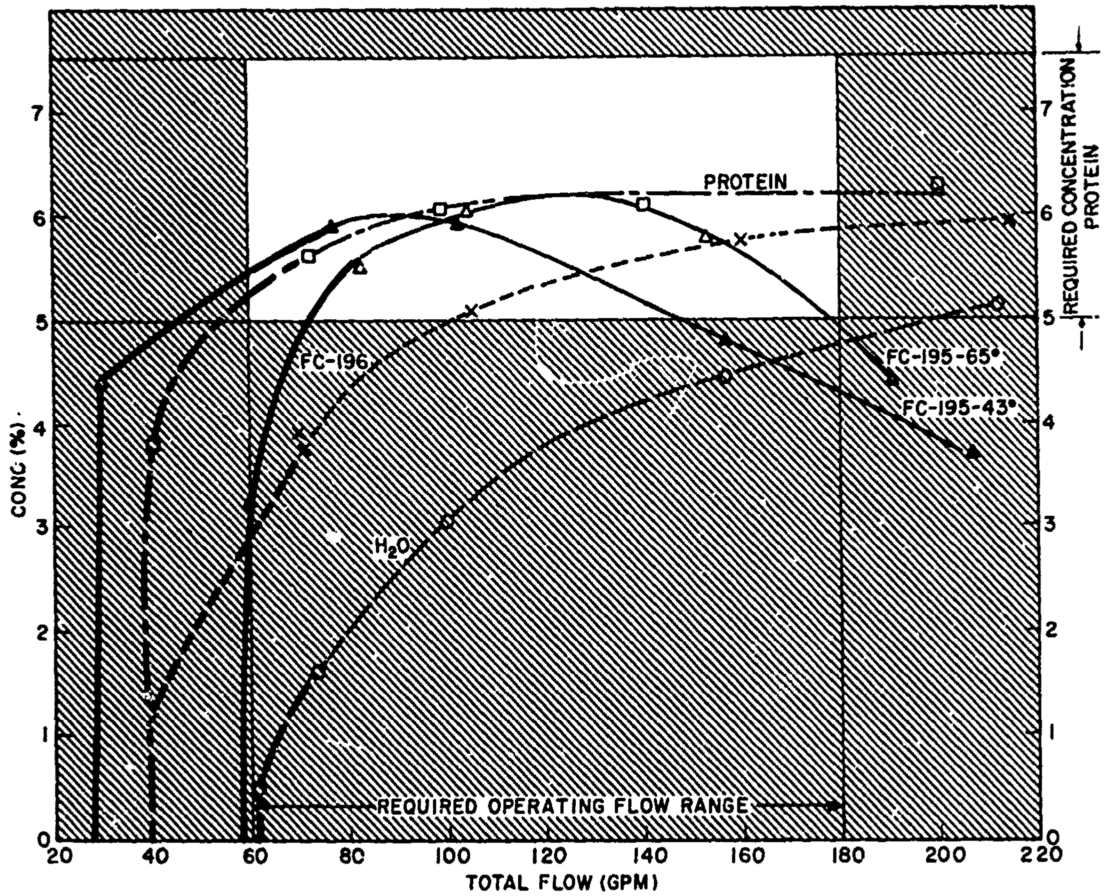


Fig. 5 — Concentration of resultant solution from class FP-180 proportioner as related to concentrate viscosity and flow rate with inlet pressure of 150 psi

regime is shown in Figs. 4 and 5 by the heavier lines extending down to the zero concentration level to the left of the priming points.

Large Water-Motor Proportioner

Most of the data for the large proportioner were obtained by disconnecting the outlet line from the concentrate pump and directing the output through a flow meter back into the supply tank. This recirculation system was used to avoid consumption of large quantities of concentrate. Fire-main pressure on the pump outlet was achieved by a throttling valve in the return line.

Two series of runs were made to observe the effect of inlet pressure, one at 110 psi and one at 150 psi. Runs were also made at both inlet pressures with and without a booster pump between the concentrate tank and proportioner. The booster pump used was a turbine-type pump model G6-BF made by Aurora Pump. Previous experience with this pump had shown that it was necessary to provide a certain amount of bleed flow from the pump to prevent heating when the pump was running against a closed discharge.

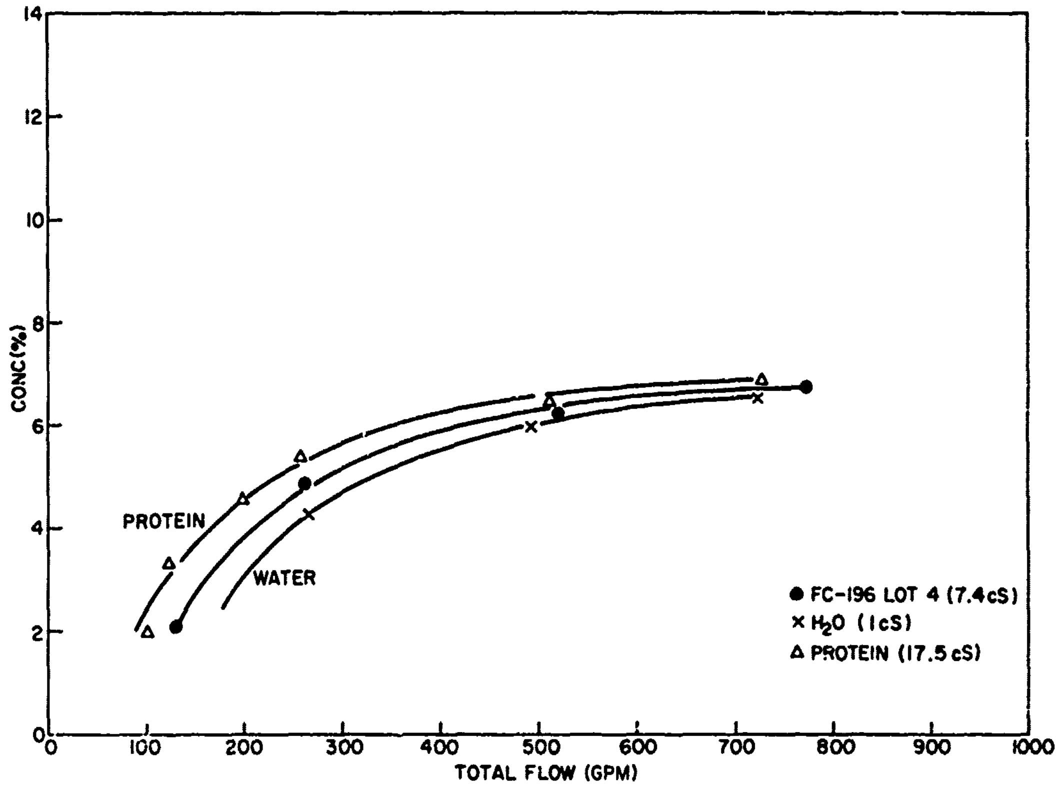


Fig. 6 — Concentration of resultant solution from 1000-gpm proportioner as related to concentrate viscosity and flow rate with inlet pressure of 110 psi

(This will occur on shipboard when all hose nozzles are closed simultaneously during fire-fighting operations.) A 1/4-inch orifice in a line leading from the pump outlet back to the suction tank permitted a drawoff of 10 to 15 gpm, which was adequate for cooling purposes but still left enough pump capacity for proportioner operation.

The performance data without the booster pump are given in Figs. 6 and 7 and with the booster pump in Figs. 8 and 9. The actual pressures developed at the inlet of the proportioner pump for the various liquids at varied flows are shown in Fig. 10.

Injection Pump Proportioner

The measured outputs of a nominal 60-gpm Blackmer vane-type positive displacement pump are presented in Fig. 11, as a function of discharge pressure and the liquid being handled. This pump is typical of those being used in the flush-deck systems for the flight deck.

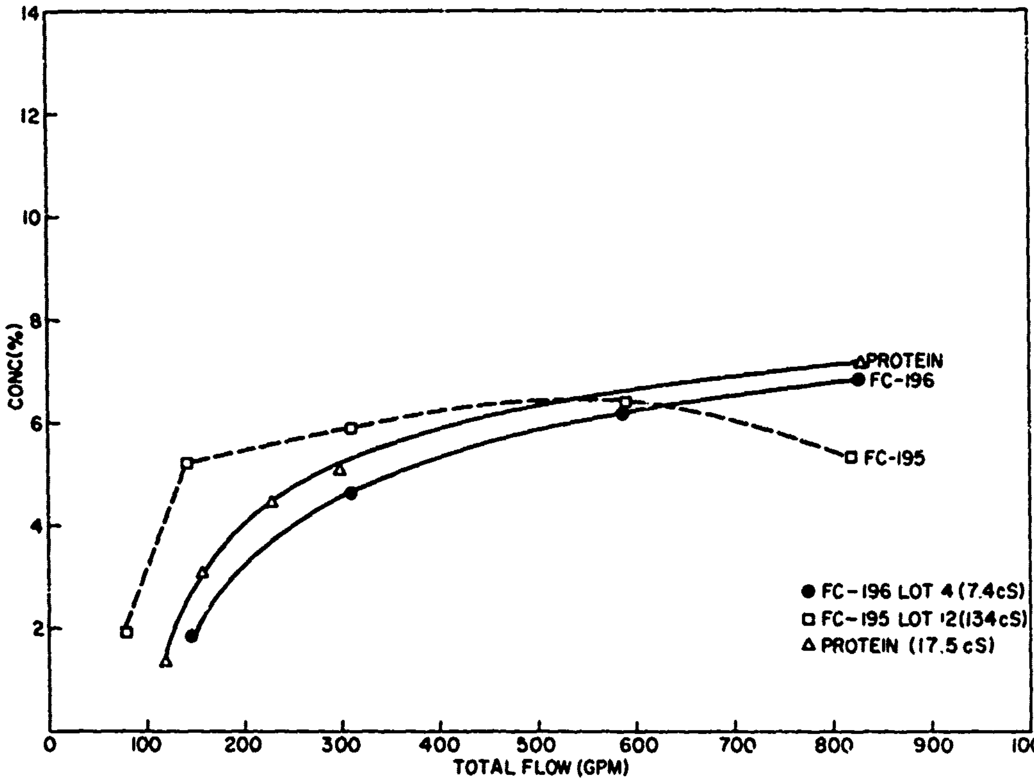


Fig. 7 — Concentration of resultant solution from 1000-gpm proportioner as related to concentrate viscosity and flow rate with inlet pressure of 150 psi

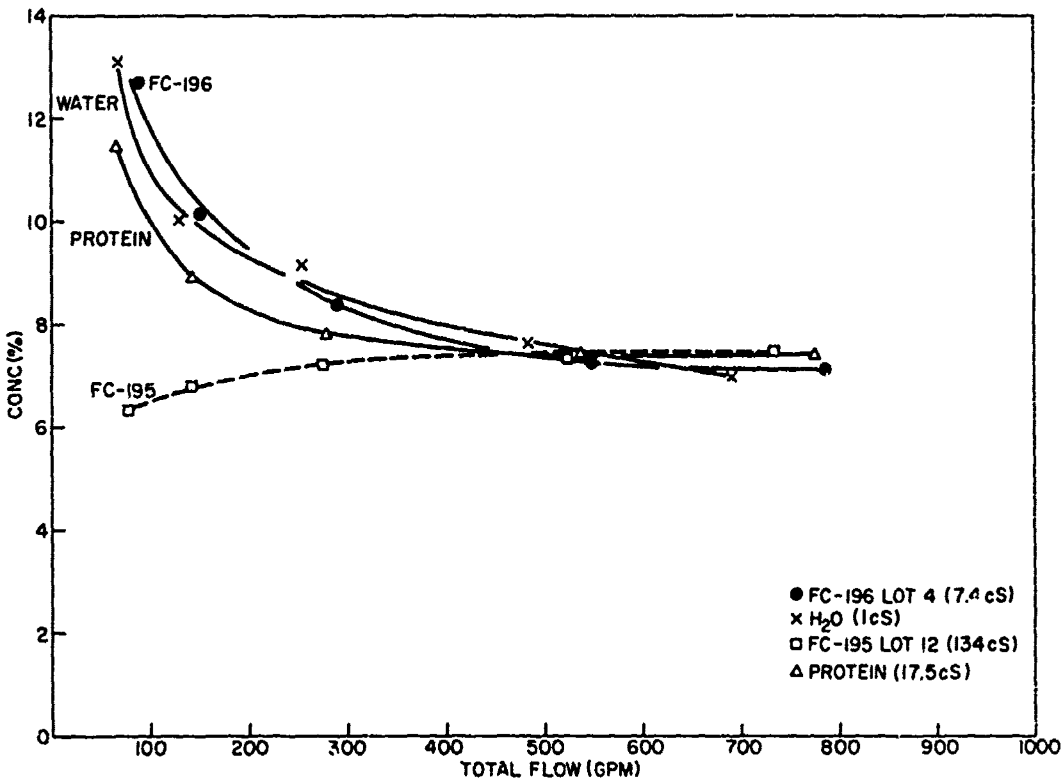


Fig. 8 — Concentration of resultant solution from 1000-gpm proportioner as related to concentrate viscosity and flow rate with inlet pressure of 110 psi and booster pump in operation

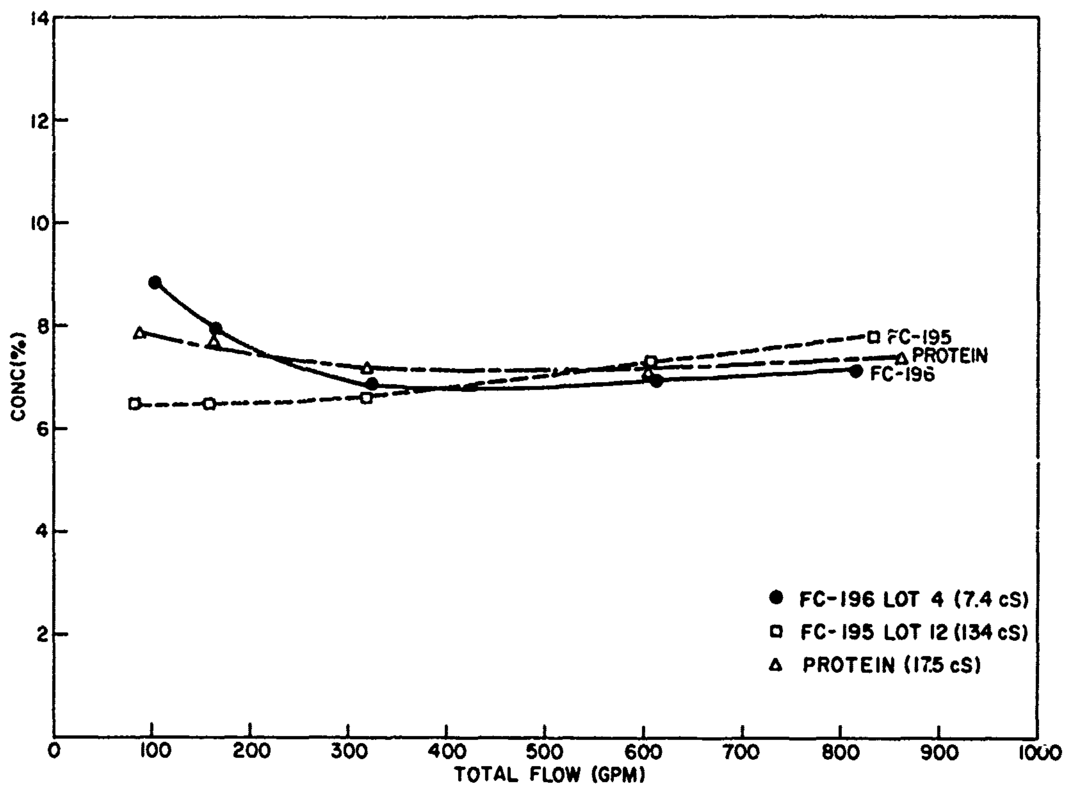


Fig. 9 — Concentration of resultant solution from 1000-gpm proportioner as related to concentrate viscosity and flow rate with inlet pressure of 150 psi and booster pump in operation

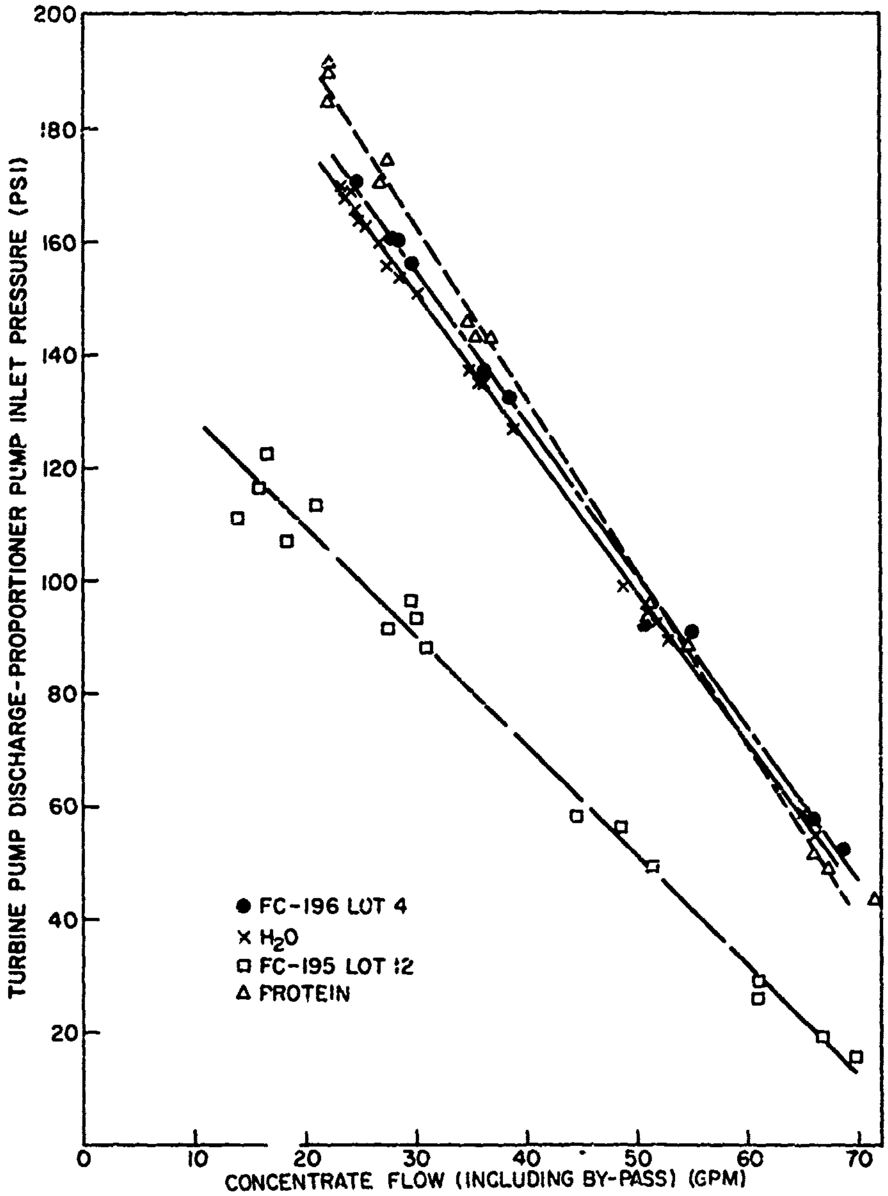


Fig. 10 — Pressure developed at inlet of the proportioner pump by use of booster pump according to concentrate and concentrate flow rate through the proportioner pump

14

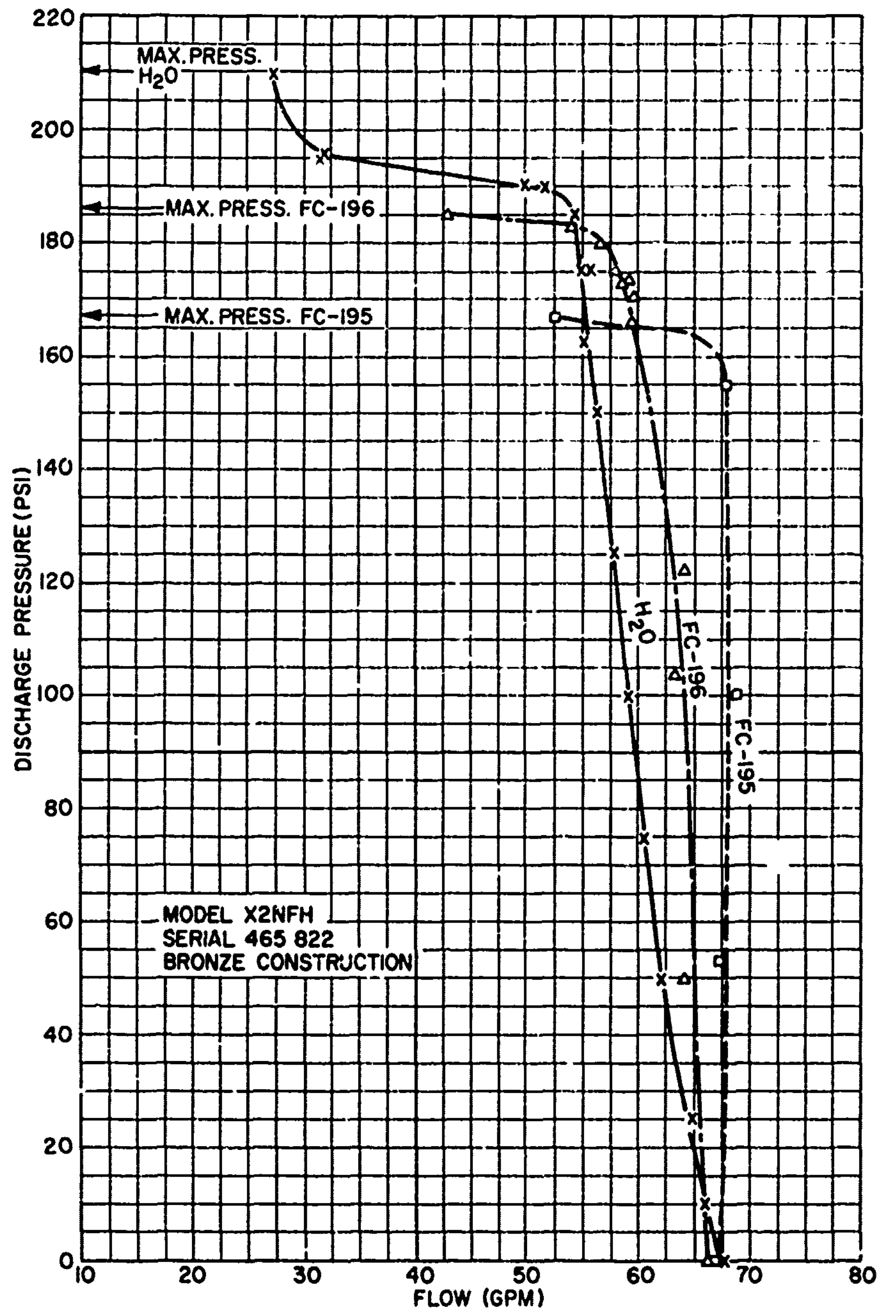


Fig. 11 — Injection pu. ¬ output as a function of the liquid being handled and discharge pressure. Also indicated are the points of opening of the internal pressure relief valve.

Figure 12 shows the construction of the bleeder valve assembly removed from the pump. The opening at the top of the assembly, as viewed, leads to the pump inlet and the bottom opening connects to the pump outlet. The adjustable valve stem serves to regulate the amount of concentrate which can be recirculated or bypassed within the pump itself, which in turn can serve to regulate the pump output. Thus, AFFF concentration is supplied to the flight deck to a fine degree. The large hexagonal nut seen on the end of the valve stem serves only as a locking nut; actual setting of the valve stem is achieved by turning a slotted head accessible through the hole in the lock nut.

The amount of liquid passing through the bleed valve is plotted in Fig. 13 as a function of the number of turns of the valve stem for the more viscous FC-195 and the less viscous FC-196 concentrates. Figure 14 shows the effect of this bypass flow on the available output of the 60-gpm (nominal) pump for the two concentrates and their mixtures.

Flow Meter Constants

Turbine-type flow meters were used in the various lines to measure the flow rates of the concentrates being handled. In many cases the flow was double-checked by timed volume checks into a calibrated receiver. The effect of the difference between the viscosities of the two concentrates on meter calibration is given in Fig. 15.

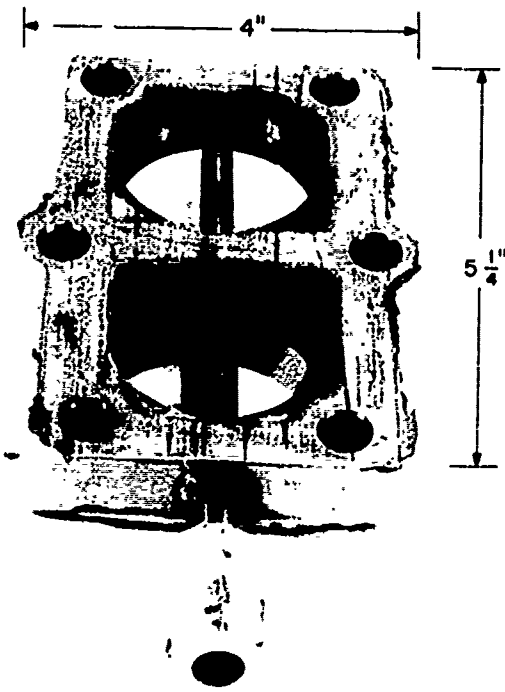
DISCUSSION

Concentrate Viscosity

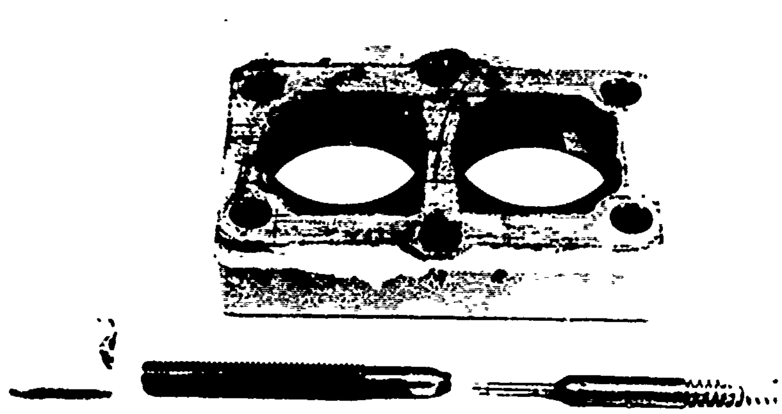
By plotting the concentrate temperatures against concentrate viscosities in the manner of the ASTM Standard Viscosity-Temperature Charts for Liquid Petroleum Products (D 341), a straight-line relationship is developed as in Fig. 1. FC-194 and FC-195 are very similar in their characteristics; FC-196 and FC-199 also have similar characteristics but appear in a distinctly lower viscosity region. It is expected that new materials developed in the future will be in this low viscosity range. The FC-196 and FC-199 liquids have a well-defined freezing point in contrast to FC-194, FC-195, and protein foam. Protein foam concentrate viscosity lies intermediate between the two groupings of AFFF.

The viscosities of mixtures of AFFF concentrates given in Fig. 2 show values lower than the straight-line that might be expected. These data, in conjunction with other data in this report on proportioner-viscosity performance, may be used to predict the proportioning characteristics of mixtures which might occur in field installations.

AFFF and protein foam concentrates are incompatible and should never be mixed in the same tank.



(a) Assembled view



(b) Exploded view

Fig. 12 — Bleeder valve assembly removed from injection pump

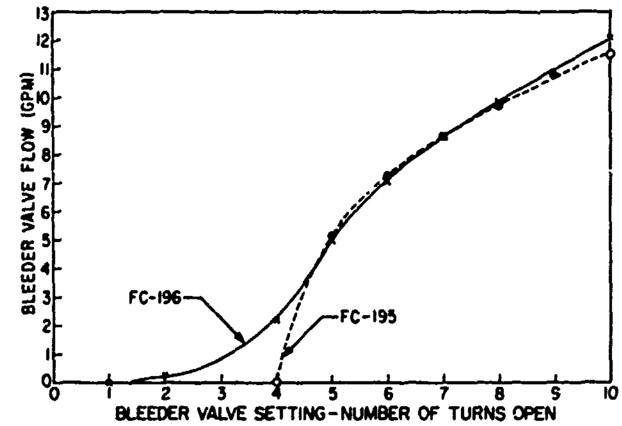


Fig. 13 — The flow rate through the bleeder valve according to concentrate viscosity and degree of valve opening

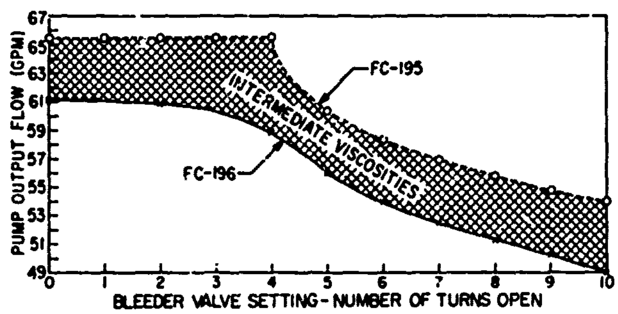


Fig. 14 — Effect of bleeder valve setting and concentrate viscosity on pump output

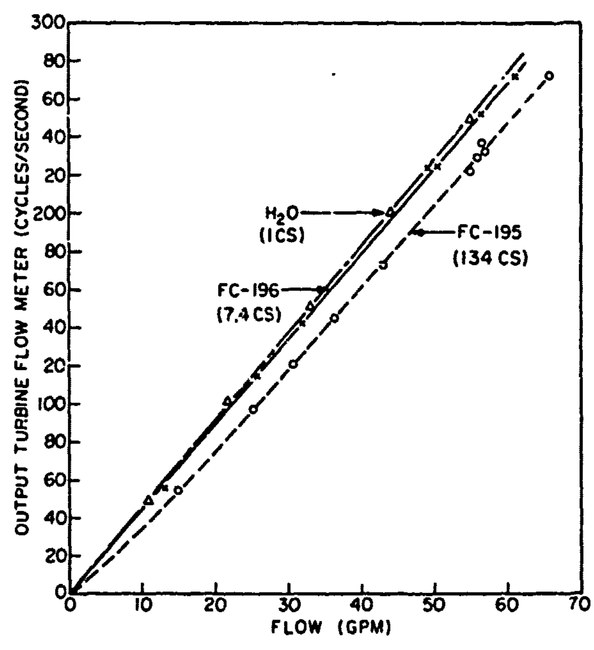


Fig. 15 — Flow meter constants as related to viscosity of liquid being handled

Nozzle Eductor Proportioner Performance

Examination of the data of Fig. 3 shows that a 6% concentration of protein foam is obtained when the eductor nozzle inlet pressure is 150 psi. This particular nozzle was designed for use with protein foam. With lower pressures the concentration increases because the water flow volume drops off with lower pressure, while the educted concentrate volume remains essentially constant. From these results it is obvious that no proportioning problems are introduced by using concentrates with viscosities lower than protein foam with the NPU or other hose-line nozzles equipped with a pickup tube. On the contrary, they will lead to solutions which are rich by as much as 50% but this is not judged to be serious because of the low total consumption rate for these devices. The use of the AFFF concentrates which have viscosities higher than protein foam may drop below 6% at low temperatures with high nozzle pressures but not to the extent where fire extinguishing capability will be impaired.

Aircraft Rescue and Fire-Fighting Vehicle Proportioners

The MB-1 and MB-5 aircraft rescue and fire-fighting vehicles using the foam pump all utilize the matching orifice method of proportioning, as described earlier. These orifices were sized for protein foam, so with FC-194 and FC-195 they should be operating on the lean side. Conversely, with FC-196, FC-199, and FC-200 they should be operating on the rich side. In addition to the added cost, running rich is an undesirable practice which could result in exhausting the concentrate supply before the water supply is exhausted so that only plain water would then be discharged from the turret or handlines.

No known data exist on the performance of these systems with the various possible concentrates or how they might be modified to obtain optimum results.

Small Water-Motor Proportioner

The performance curves for the 60- to 180-gpm capacity water-motor proportioner are given in Fig. 4 for an inlet pressure of 110 psi and in Fig. 5 for 150 psi. It is observed that the protein concentrate, again for which the unit was designed, falls well within the requirements for both the high and low inlet pressures. The lower-viscosity FC-196 does not reach the 5% concentration level until the flow rate reaches 100 gpm, and with the lowest-viscosity liquid, water, it never does achieve the 5% level. The liquids of higher viscosities, FC-195 at 65° and 48°F, do well at the low and moderate flow rates but their rates of intake drop off at high flow rates when the increased drag resistance becomes appreciable.

The points farthest left on the heavy portions of the curves (Fig. 4) represent the minimum flow rate for pump priming and indicate that this flow was about 55 gpm, and as pointed out previously, independent of the liquid being used as the concentrate. With the higher inlet pressure, Fig. 5, the minimum flow required for priming increased to about 70 gpm; faster pump speeds were needed to overcome the increased slip resulting from higher pressures at the concentrate pump outlet as well as the water-motor inlet.

These results reveal that a critical situation exists with these units because the minimum priming flow requirement often exceeds the flow rate of a single hose line and nozzle which it is supposed to accommodate. In a trial using a single NPU nozzle operating with the proportioner inlet pressure at 80 psi, 30 seconds were required for priming. With inlet pressures higher than 80 psi, no priming took place. Fixed fire-extinguishing systems for shipboard machinery spaces have this proportioner permanently piped in place below the concentrate storage tank and the pump suction is flooded instead of having a 2- to 3-ft lift. Although this difference in pump suction head is quite small, a total of 4 ft in relation to the pump discharge head, its effect on reliability of priming should be investigated in future studies.

Examination of the extreme left-hand portions of the curves in Figs. 4 and 5 illustrates what happens as the flow rate (and pump speed) is reduced after the different viscosity concentrates had primed and filled the pump. Here it is obvious that viscosity played an important role in holding pump prime with the more viscous solutions functioning better at the lower flow rates.

Large Water-Motor Proportioner

Figures 6 and 7 summarize the performance data for the large, 200- to 1000-gpm proportioner for operation without a booster pump at the two inlet pressures of 110 and 150 psi. As was the case with the small proportioner, the more viscous concentrates produced higher-strength solutions at the low flow rates; however, the most viscous concentrate, FC-195, did begin to fall off in flow when the primary (water) flow rate reached 600 gpm.

The effects of operating the booster pump to supercharge the proportioner pump are shown in Figs. 8 and 9. This effect was most pronounced at low flows, low inlet pressure, and low-viscosity concentrates where the volume of forward slip was relatively greater.

From these results it may be concluded that the Aurora Turbine booster pump with the third generation Hale proportioner will permit good operation with one flight deck 1-1/2-inch hose line fitted with a 60-gpm nozzle. The high concentration of AFFF in the solution delivered is not believed to be a serious problem because of the low consumption rate at these relatively low flow rates.

Booster Pump Operation

The curves of Fig. 10 show that the discharge pressures of the turbine pump drop rapidly as the "drawoff" rate increases. However, the increased speed of the proportioner picks up the "slack" and maintains the concentration at a good level (Figs. 8 and 9). Figure 10 also shows that the high viscosity of FC-195 substantially reduces the available pump discharge pressure in comparison with the other concentrates. This is probably the big factor in the lower concentration of FC-195 seen in Fig. 8 in the region of low flow rates.

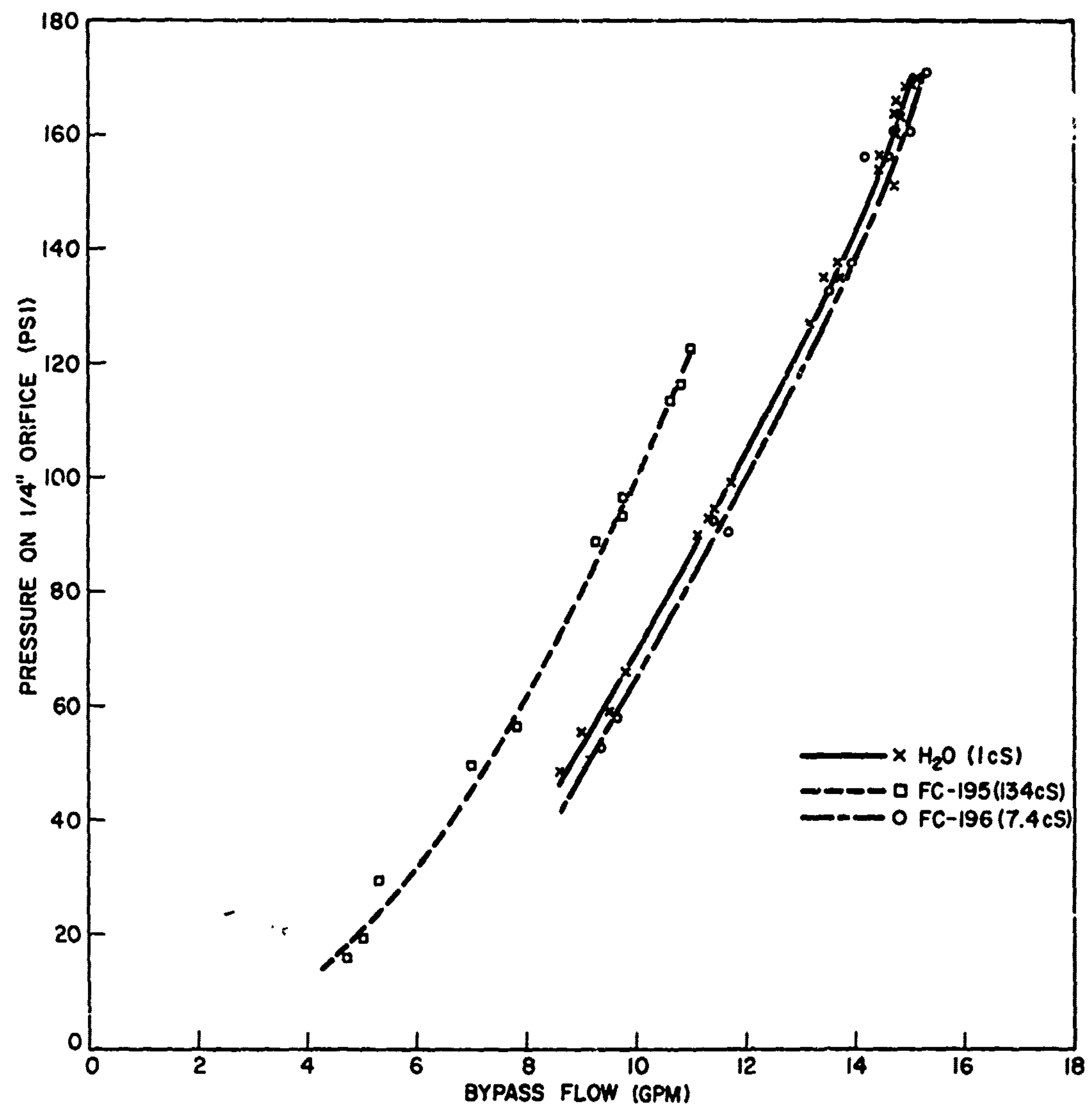


Fig. 16 — Volume of concentrate bleed flow through 1/4-inch-diameter orifice as a function of viscosity and pressure

The volumes of flow being recirculated back into the concentrate storage tank through the 1/4-inch orifice to provide heat removal are plotted in Fig. 16 as a function of pump outlet pressure and concentrate viscosity. This volume is deducted from the total pump output volume and not available to the proportioner.

Observations on Proportioner Pump Slip

To determine the slip characteristics of the gear pump used on the proportioner, the volume of slip in each run was calculated from the difference between theoretical displacement and measured output. After first plotting the slip volume against pressure

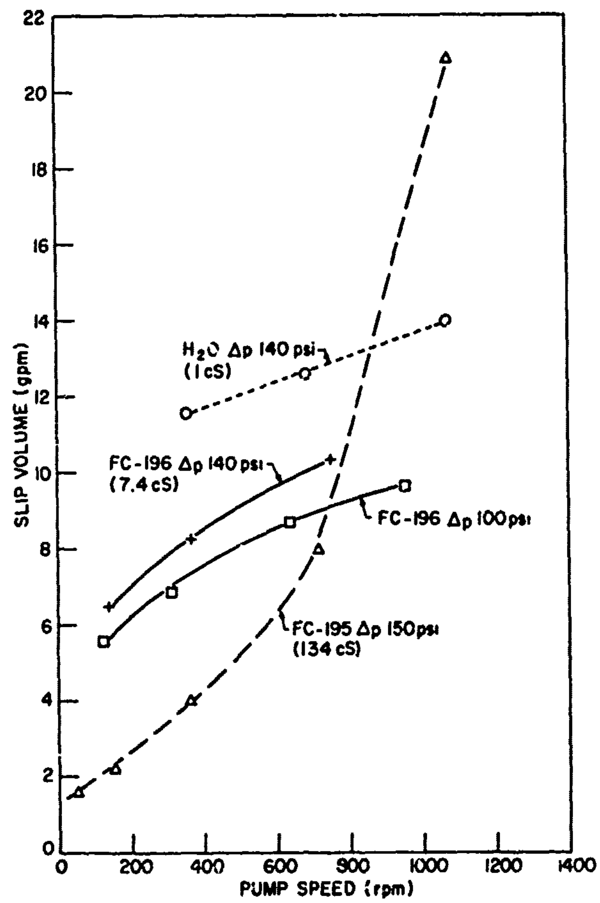


Fig. 17 — Volume of proportioner pump slip as related to pump speed and concentrate viscosity

drop across the pump, it was found that the volume was highly influenced by the speed of the pump, perhaps even more so than by pressure differential. Therefore, the results were plotted as volume of slip against pump speed, as shown in Fig. 17. The influence of viscosity is readily seen from the data given for three materials at approximately the same pressure differential of 150 psi. As would be expected, the most viscous solution (FC-195) suffered the least and the least viscous (water) slipped considerably under the same conditions of pump speed and pressure drop.

A pronounced break in the FC-195 curve occurs at 700 rpm. It is suggested that this value represents the onset of cavitation at the pump inlet and not a sudden increase in the amount of slip.

Although the amount of data was limited, it appeared that the volume of slip varied considerably with the direction of the pressure differential. With the booster pump in operation it was possible, of course, to have a higher pressure at the pump inlet than at the pump outlet and the slip would go forward in contrast to normal operation (backward slip, from outlet to inlet). Not only was the observed slip volume considerably less in the forward direction for the same pressure differential and pump speed but the relationship with speed appeared to be the opposite of that in Fig. 17, i.e., the slip volume decreased with increasing pump speed.

Injection Pump

The injection pumps used with the washdown system were purchased by the shipyards that installed the flight deck nozzle systems in accordance with the design requirements of flow and pressure. NRL purchased a bronze pump of 60-gpm capacity as being typical of shipboard equipment. (The first installation on the CVA-66 used this pump in stainless-steel construction which has greater internal clearances.) The internal pressure relief valve setting was adjusted to the same setting as those pumps being supplied to the shipyards.

By first running the pump on water it was found that the pressure regulator would prevent the outlet pressure from exceeding 210 psi. However, before this maximum was reached, the valve was unseating and permitting an internal recirculation of liquid. The data of Fig. 11 show that the unloading began at about 185 psi and the available output from the pump was appreciably reduced above this pressure. It is also shown in Fig. 11 that the intermediate viscosity liquid, FC-196, began to bypass within the pump at an even lower pressure and the more highly viscous FC-195 at a still lower pressure. There is no ready explanation as to why the point of opening of the regulating valve varied with the different viscosity liquids.

The actual minimum pump outlet pressure required in this system aboard ship must be the fire-main pressure at the 03-deck level plus the static head from the second deck level plus the friction loss. On this basis approximately 200 psi should be available at the pump and any unseating of the regulator below this pressure could result in bypass within the pump with consequent low concentration of solution being fed to the flush-deck nozzles. Such a condition has been found while conducting operational tests on newly installed aircraft carrier systems. All regulating valves should be tested after pump installation while pumping concentrate.

The amount of slip for each of the liquids can be seen in Fig. 11. The rate for the viscous FC-195 was practically nil up to about 160 psi at which point the regulating valve opened; at this same pressure the water slippage rate was 18%. Some compensation has been allowed for this factor by designing the pump to have a displacement slightly greater than the rated 60-gpm output.

The bleeder valve assembly of Fig. 12 was another unknown adjustment in setting up the pump, since it had not been tested by pumping the various liquids. The data from Fig. 13 show that 10 turns of the control stem moved it from the shutoff position to the wide-open position, and at the latter setting the flow rate was about 12 gpm for both liquids. The viscosity was influential in the flow rate only while the valve was first being opened. The net effect of combining the bleeder valve setting and the pump slip is given in Fig. 14. With FC-195 the final solution concentrations of a 1000-gpm nozzle system could be varied from 6.1 to 5.2% and with FC-196 from 5.8 to 4.7% by adjustment of the bleeder valve.

Information contained in Figs. 11 and 14 should be of value to the shipyards in making installation adjustments and to the ships in keeping the systems within operational limits.

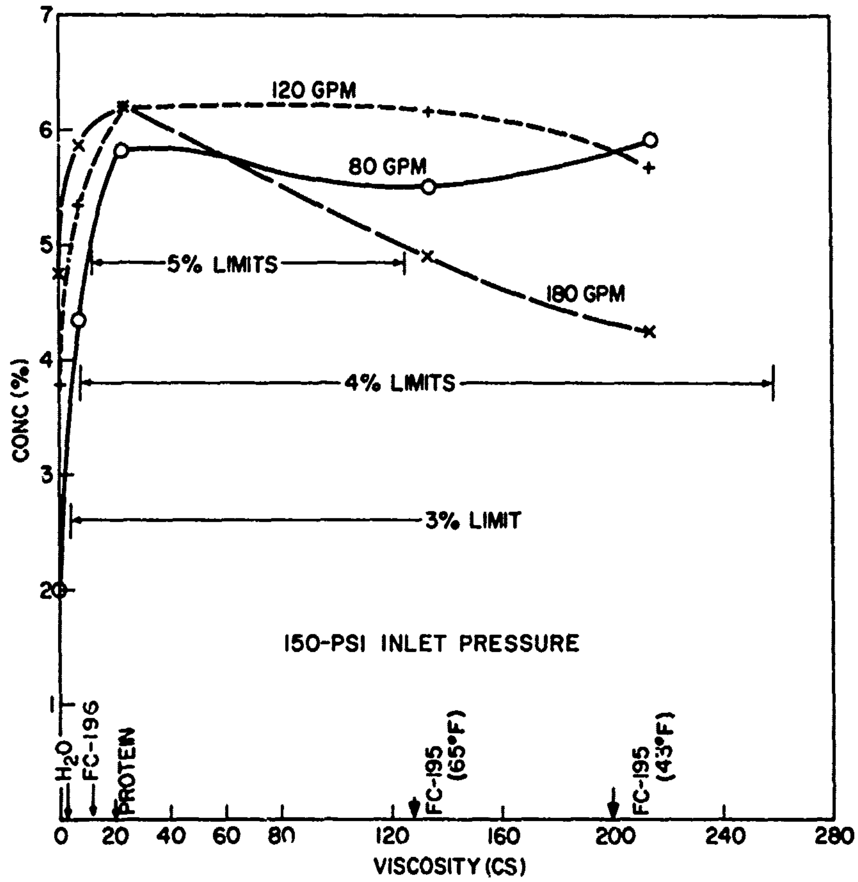


Fig. 18 — Concentration of solution output from class FP-180 water-motor proportioner indicating upper and lower viscosity limits to achieve 3, 4, and 5% solutions

Establishment of Viscosity Limits

With the performance data obtained with currently used proportioning equipment, indicating the importance of concentrate viscosity, it becomes desirable to establish upper and lower viscosity limits for the concentrate in order to achieve the desired solution strength for fire suppression purposes. Data from the earlier figures have been replotted in a manner to implement this selection in Figs. 18 and 19. Figure 18 contains the data from the small water-motor proportioner, and Fig. 19 contains values for the large water motor. A family of three curves is shown for each unit representing a minimum, middle, and high flow rate with the inlet pressure held constant at 150 psi. The liquids handled are identified on the horizontal, or viscosity, axis.

The general characteristics are the same in both figures. The low flow conditions are most sensitive to a low viscosity, and the solution strength builds rapidly as the viscosity increases. Thus, the minimum viscosity for a concentrate must be based on the minimum-rated flow rate, but the exact value will in turn depend on the minimum desired solution strength. For example, if it has been established that a 5% concentration

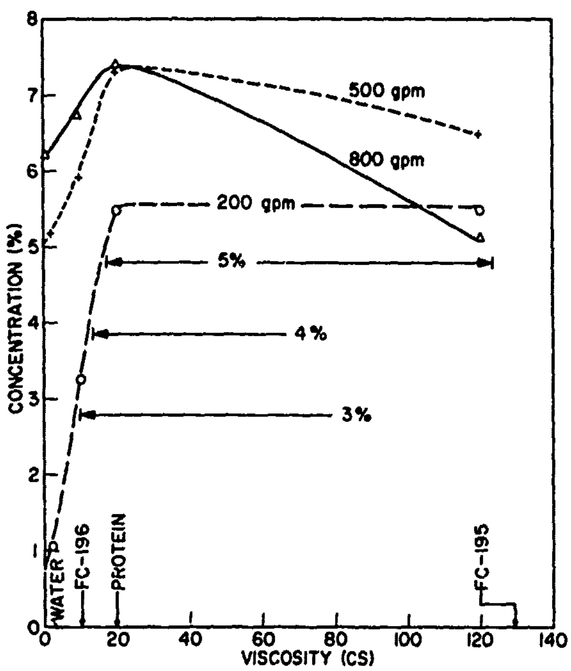


Fig. 19 — Concentration of solution output from 1000-gal./min of water indicating upper and lower viscosity limits to achieve 3, 4, and 5% solutions

of an agent is required, as was the case with protein foam, Fig. 18 shows that a viscosity of 20 cS just reaches 5% at the minimum flow of 80 gpm when the inlet pressure was 150 psi. Proceeding across the graph shows the 5% level intersecting the 180-gpm (maximum-rated flow) curve at approximately 120 cS. This span of viscosity values, 20 to 120 cS, to produce a minimum of a 5% solution is indicated in Fig. 18. When lower concentrations are acceptable, the limits widen accordingly. For 4% solutions, the low limit would be 7 cS and the upper limit is estimated to be about 275 cS; for 3% solutions, the lower limit is 4 cS, with no upper limit.

From Fig. 19 the corresponding limits are judged to be 17 to 125 cS for a minimum of 5%, 12 cS for the low limit for 4%, and 9 cS for the low limit for 3%. The upper limits were not defined for the large water-motor proportioner for 3 and 4% solutions because the maximum-rated flow of 1000 gpm was not reached during the tests.

The agreement between the proportioning units is fairly good, and the averaged values should be significant in defining limits of viscosity for the concentrates to be handled in such equipment. To obtain better proportioning performance onboard ships it would be helpful to have such limits as a part of the AFFF concentrate specification MIL-F-24385.

Another phase of the overall NRL advanced damage control project involves determination of the minimum level of AFFF concentration strength required for adequate fire performance criteria.

It is interesting to note that the optimum proportioning performance, i.e., near 6% over a wide range of flow rates, seems to peak at a viscosity of about 20 cS which is the viscosity of protein foam at normal room temperature. This is not surprising, however,

because the proportioners were designed to handle this product and conceivably a device could be built to handle the low-viscosity AFFF concentrates in a similar manner. Such a redesign to closer tolerances and replacement of existing equipment would be very costly, however. It is also interesting to note that a 6% concentration level is never achieved at the low flow regimes even though they are within the range ratings of the devices.

The basic construction of the water-motor proportioner is no different than the injection pump and the slip involved is no different under the same operating conditions. The reason that the water-motor unit is questionable while the injection unit operates well is that the latter runs at a constant speed while the former must operate over a 1 to 5 speed range. Because of this speed variation, the slip goes from a nominal 10 to 15% up to a phenomenal 70% at low speeds, and there is no way to compensate for this variation in the existing equipment.

Miscellaneous

Data were obtained in two areas which did not relate directly to the problem at hand but which relate to further testing and design. The turbine-type flow meter is a very convenient method of indicating and recording flows when connected into the appropriate electronic devices. Normally the meters are calibrated with water, but when used with other liquids their differing viscosities must be taken into account. The correction factors required in using the AFFF concentrates are given in Fig. 15.

In connection with the use of orifices for control of AFFF concentrate flow for pump bleed cooling and recirculation for maintenance testing purposes, constants are needed for the usual flow equation. Such data are available from Fig. 16.

CONCLUSIONS

The AFFF concentrates currently being produced are lower in viscosity than the earlier AFFF materials and also lower than the previously used protein foam concentrates for which most of the existing fire-fighting equipment in the Navy was designed. Viscosity of the concentrate plays an important role in the functioning of proportioning equipment used to add concentrate at a proper amount to a flowing water supply to the foam application devices.

The use of the new lower-viscosity AFFF concentrates results in solutions which are rich from eductor- and orifice-type equipment not specifically designed for the low viscosity. Conversely, equipment which depends on positive displacement pumps, such as water-motor proportioners and injection systems, will produce weak solutions unless they are specifically designed for low-viscosity concentrates.

The unloading points of pressure-regulating valves may be influenced by the viscosity of concentrate being handled as opposed to water.

RECOMMENDATIONS

It is recommended that the specification requirements for AFFF concentrate be amended to include a minimum viscosity value. A minimum value of 20 cS (25°C) is suggested. The present maximum of 80 cS (5°C) should be retained.

If the above recommendation cannot be accomplished, it is recommended that the minimum AFFF solution concentration for good fire suppression performance be established and the adequacy of present shipboard proportioning equipment be reevaluated in this light.

It is recommended that the proportioning devices on the aircraft rescue and fire-fighting vehicles (MB-1 and MB-5's), which can be readily modified, be adjusted to account for the viscosity of the new concentrates.

ACKNOWLEDGMENTS

The authors express their appreciation to Mr. J. W. Porter for his valuable assistance in collecting the data summarized in this report.